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## OBSERVATIONS UPON THE NITROGEN OF THE PARTICULATE MATTER IN THE SEA <sup>1</sup>

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*(From the Woods Hole Oceanographic Institution)*

The present investigation has been undertaken in order to secure data on the amount of organic matter present in particulate form in different regions of the sea. Such information is of importance because in the cycle of life in the sea a very large part of the living matter must occur as nanoplankton. These organisms, together with the more resistant portions of decomposing organisms, detritus, make up the particulate matter which has been studied. Data have accumulated rapidly concerning the dissolved substances such as nitrate, phosphate, etc. which appear in the later stages of the cycle of decomposition but at present almost nothing is known of the quantitative occurrence of these materials while they are bound up in organized matter.

For practical analytical reasons, as well as because of the supreme importance of nitrogenous compounds in the biological cycle, the distribution of particulate matter has been measured in terms of the nitrogen content. Water samples of one to four liters were collected with Nansen bottles and preserved by the addition of 20 cc. of formalin per liter. The particulate matter was concentrated according to the centrifugation method of Steemann-Nielsen and von Brand (1934). The nitrogen content was determined according to von Brand's (1935) modification of Krogh and Keys' (1934) method. In every case duplicate analyses were performed. With a few exceptions, in the case of very low values, they agreed in the range of 10 to 15 per cent. All organisms of about the size of copepods or above were removed. The values obtained thus represent the nitrogen content of the nanoplankton and detritus.

Throughout the whole procedure every care was taken in order to avoid contamination with nitrogen-containing substances. There were

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no indications of any great amount of contamination, but the possibility of a certain degree of contamination cannot be excluded with certainty (for example, from the wire or the closing mechanism of the Nansen bottles). It is not impossible, on the other hand, that during the concentration a certain amount of the particulate matter was lost. The method of concentration gave very satisfactory results with nordic plankton (Stemann-Nielsen and von Brand, 1934); but with Mediterranean plankton considerable losses were reported (Bernard and Fage, 1936). This may, however, be due to slight modifications of technique. Dr. John Fuller (personal communication) tested the method with a diluted culture of *Nitzschia closterium*. He compared the values obtained after centrifugation with those calculated from previous direct counts on the undiluted culture. He recovered 94 per cent, whereas Bernard and Fage lost 50 per cent of *Nitzschia longissima*.

In Table I are summarized the analytical data from which the results given in Table IV are derived. They demonstrate the order of

TABLE I  
*Accuracy of the nitrogen method*

Water centrifuged for the single analysis in milliliters	Naphthyl red in milliliters						Naphthyl red in milliliters corresp. to 1γ N	γN in particulate matter	
	I. Analysis			II. Analysis				I. Analysis	II. Analysis
	Control precip.	Organ. precip.	Diff.	Control precip.	Organ. precip.	Diff.			
200	2.88	1.30	1.58	2.70	1.00	1.40	0.45	3.5	3.1
100	3.40	2.45	0.95	3.39	2.19	1.20	0.44	2.2	2.7
200	3.27	1.83	1.44	3.31	1.63	1.68	0.44	3.3	3.7
100	2.75	1.34	1.41	2.75	1.46	1.29	0.47	3.0	2.7
100	3.24	1.08	2.16	3.00	0.50	2.50	0.50	4.3	5.0
100	3.18	1.59	1.59	2.96	1.46	1.50	0.45	3.5	3.2
200	3.23	0.65	2.58	3.17	0.32	2.85	0.45	5.7	6.3
200	3.03	0.34	2.69	2.73	0.30	2.43	0.44	6.1	5.5

accuracy which can be expected from the nitrogen method. The percentage error is about the same in most of the data reported in the other tables. The N values actually determined were also in most other cases approximately as high as those shown in Table I. In cases where only small amounts of nitrogen were expected, greater amounts of water were centrifuged (for the single analysis of the deep sea samples usually 1,000–2,000 ml., for those of the Gulf of Maine 200–400 ml.). In some analyses of the deep sea samples with nitrogen values below 1γ N

in the single analysis the percentage error was appreciably higher. The greatest percentage difference observed between two analyses of the same water sample occurred in the 1,300-meter sample of the Sargasso Sea station: I. analysis  $0.40\gamma$  N, II. analysis  $0.85\gamma$  N.

Confidence in the quantitative adequacy of the methods employed is also given by a comparison of the results obtained at mid depths in the Gulf of Maine (Table V) with similar estimates of the phosphorus present in particulate form in these waters. Analyses made by Dr. Homer Pyne Smith indicate that about  $5\gamma$  per liter of  $\text{PO}_4$  is present throughout the year in a form which can be separated by filtration. This is one-third the quantity of nitrogen found in particulate form; exactly the ratio to be expected in particles of organic origin.

### RESULTS

Table II shows the vertical distribution of the nitrogen in the particulate matter in the Sargasso Sea. The relatively low surface value of  $8.4\gamma$  per liter is in accordance with the scarcity of plankton in this

TABLE II

*Vertical distribution of the nitrogen of the particulate matter in the Sargasso Sea.*  
Atlantis Station 2639. Latitude N.  $35^\circ 08'$ . Longitude W.  $66^\circ 30'$ .  
July 10-11, 1936.

Depth in meters	Nitrogen $\gamma$ per liter	Depth in meters	Nitrogen $\gamma$ per liter	Depth in meters	Nitrogen $\gamma$ per liter	Depth in meters	Nitrogen $\gamma$ per liter
0	8.4	500	1.4	1,100	.2	2,000	1.4
50	5.0	600	0	1,200	.2	2,250	2.8
100	3.4	700	.7	1,300	.3	2,500	.5
200	2.3	800	1.1	1,400	1.6	2,750	.8
300	2.0	900	.8	1,600	1.7	3,000	2.3
400	1.4	1,000	1.6	1,800	2.9	4,500-4,750	0

part of the Atlantic. The amount of nitrogen decreases with depth, first rapidly, then more slowly until it is only a fraction of  $1\gamma$  per liter between 1,100 and 1,300 meters depth. It is apparent that in the deeper layer the values are again somewhat higher. Between 1,400 and 3,000 meters they vary from .5 to  $2.8\gamma$  per liter. In the deepest sample the nitrogen content was so low that it could not be determined in the particulate matter of the 1.8 liter of water available. The determinations demonstrate that at least in the upper 3,000 meters everywhere particulate organic substance is in suspension. Of course, it cannot be stated that it represents the amount of living substance. It is reasonable to

expect that at least a part is due to the residues of dead organisms or to solid excreta.

A similar series of determinations was secured from the water on the outer slope of Georges Bank (Table III). The distribution of

TABLE III

*Vertical distribution of the nitrogen of the particulate matter in the offshore waters.*  
Latitude N. 40° 20', Longitude W. 67° 39'. July 24, 1936.  
Depth of station, 1,000 meters.

Depths in meters	Nitrogen γ per liter
0 .....	29
50 .....	11
100 .....	7
200 .....	4.7
300 .....	3.6

nitrogen, which shows a progressive decrease from the surface downward to 300 meters, is similar to that occurring at comparable depths in the Sargasso Sea. In the coastal water the nitrogen values are about twice as high as in mid-Atlantic at 50 to 300 meters, and the contrast is even greater at the surface.

A series of determinations has been carried out on surface samples from the region of Georges Bank in order to study the variability in a small area (Table IV). With the exception of the very high value of 47γ N per liter, all figures lie within the range of 18–34γ N per liter.

TABLE IV

*Horizontal distribution of the nitrogen of the particulate matter of surface water near Georges Bank.*

Date	Position		Nitrogen γ per liter
	Latitude N.	Longitude W.	
July 21, 1936 .....	40° 07'	69° 02'	18
July 21, 1936 .....	40° 09'	69° 04'	24
July 23, 1936 .....	40° 16'	68° 08'	18
July 24, 1936 .....	40° 20'	67° 39'	29
July 25, 1936 .....	41° 21'	66° 07'	47
July 23, 1936 .....	41° 22'	66° 08'	34
July 23, 1936 .....	40° 22'	67° 52'	30
July 26, 1936 .....	40° 27'	67° 42'	29

In the Gulf of Maine water was studied from three deep stations and one shallow station. The results are summarized in Table V. The

distribution of the particulate matter in the upper 40 meters was irregular, but fell very nearly in the range of the values from the surface water near Georges Bank. It is reasonable to assume that the differences found are due to an irregular distribution of the phytoplankton (*cf.* Gran, 1933; Gran and Braarud, 1935). Below 40 meters the conditions in the three deeper stations are on the whole similar. We find at intermediate depths a relatively small amount of particulate matter,

TABLE V

*Vertical distribution of the nitrogen of the particulate matter in the Gulf of Maine.*  
Depths not corrected for wire angle.

Atlantis Station No.				
	2642	2644	2643	2654
Date.....	Aug. 8, 1936	Aug. 18, 1936	Aug. 10, 1936	Aug. 19, 1936
Position....	40° 46' N. 71° 31' W.	41° 53' N. 69° 24' W.	42° 19' N. 69° 17' W.	42° 59' N. 70° 12' W.
Depth of station...	64 meters	ca. 200 meters	229 meters	ca. 160 meters
Depth of sample, m.	Nitrogen in $\gamma$ per liter	Nitrogen in $\gamma$ per liter	Nitrogen in $\gamma$ per liter	Nitrogen in $\gamma$ per liter
0	23	22	12	34
20	25	19	—	29
40	20	28	15	12
60		11	11	10
80		13	10	13
100		11	10	17
120		10	11	—
140		10	17	14
160		11	17	15
180		16	14	
200		16	14	
215			15	

whereas in the deeper layers the amount is always again higher. It should be noticed that both the minima and maxima are within very narrow limits the same at the three stations (9–10 and 16–17 $\gamma$  nitrogen per liter respectively). The differences in the depths at which the minimum and maximum concentrations of nitrogenous particulate matter occur are doubtless due to hydrographic as well as biological causes. Much more information is required before they can profitably be discussed. The striking feature of the waters of the Gulf of Maine in contrast to those from offshore is the higher and more uniform concentration of the particulate matter in the subsurface layers. May this not

be explained by the consideration that in a coastal basin particulate matter cannot sink out of reach of the tidal currents, which extend even to the bottom, and is thus kept more uniformly in suspension?

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#### SUMMARY

The distribution of nitrogen contained in the particulate matter suspended in the sea has been studied in the Sargasso Sea, on the outer slope of Georges Bank, and in the Gulf of Maine. In the oceanic water the concentration of nitrogenous particulate matter declines sharply with depth to 500 meters and tends to increase slightly below 1,400 meters. On the outer slope of Georges Bank the distribution is similar down to 300 meters, but the concentrations are about twice as great as in mid-ocean at comparable depths. In the Gulf of Maine the nitrogenous particulate matter is more uniformly distributed with respect to depth and is present in greater amounts in the subsurface water than on the outer slope of Georges Bank.

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